SECOND INTERNATIONAL INDIAN OCEAN EXPEDITION (IIOE-2)

A Basin-Wide Research Program

Science Plan Addendum

Hood, R. R., F. Al-Yamani, L. E. Beckley, G. L. Cowie, N. D'Adamo, J. Hermes, H. T. Kobryn, K. Kumar, A. Lotiker, M. K. Roxy, A. Modi, P. Rama Rao, M.-A. Sicre, P. N. Vinayachandran (Eds.)

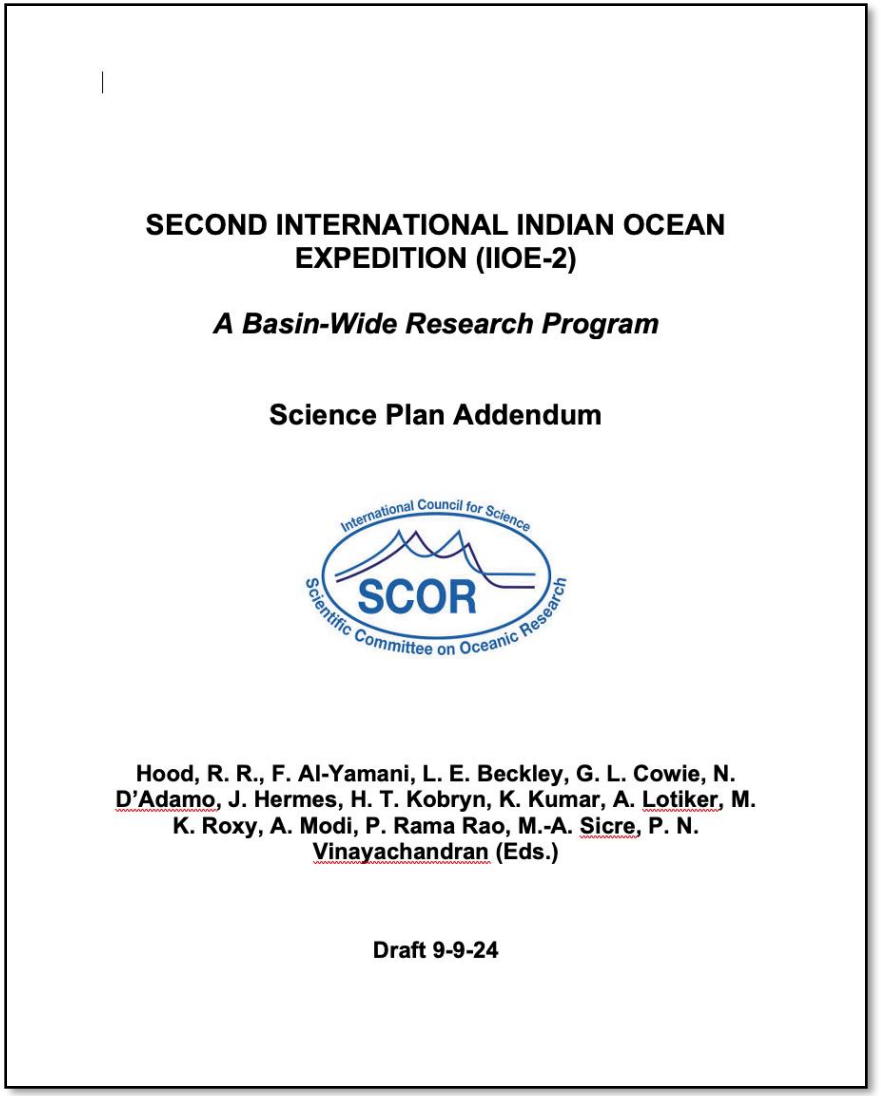
Draft 9-9-24

Development of the IIOE-2 Science Plan Addendum:

- The Addendum to the IIOE-2 Science Plan builds upon concepts and strategies formulated and discussed at three SCOR and IOC-sponsored meetings (convened in Perth, Western Australia, February 6-7, 2023; in Hyderabad, India, November 28-30, 2023; and in Lombok, Indonesia, March 4-5, 2024).

- These meetings included scientists from Indian Ocean rim nations, eastern Asia, Europe and North America.

- The meeting in Hyderabad was dedicated to the development of the Addendum, providing several key presentations, discussion notes and an outline for the document.



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Science Plan Addendum

International Council for Science
SCOR
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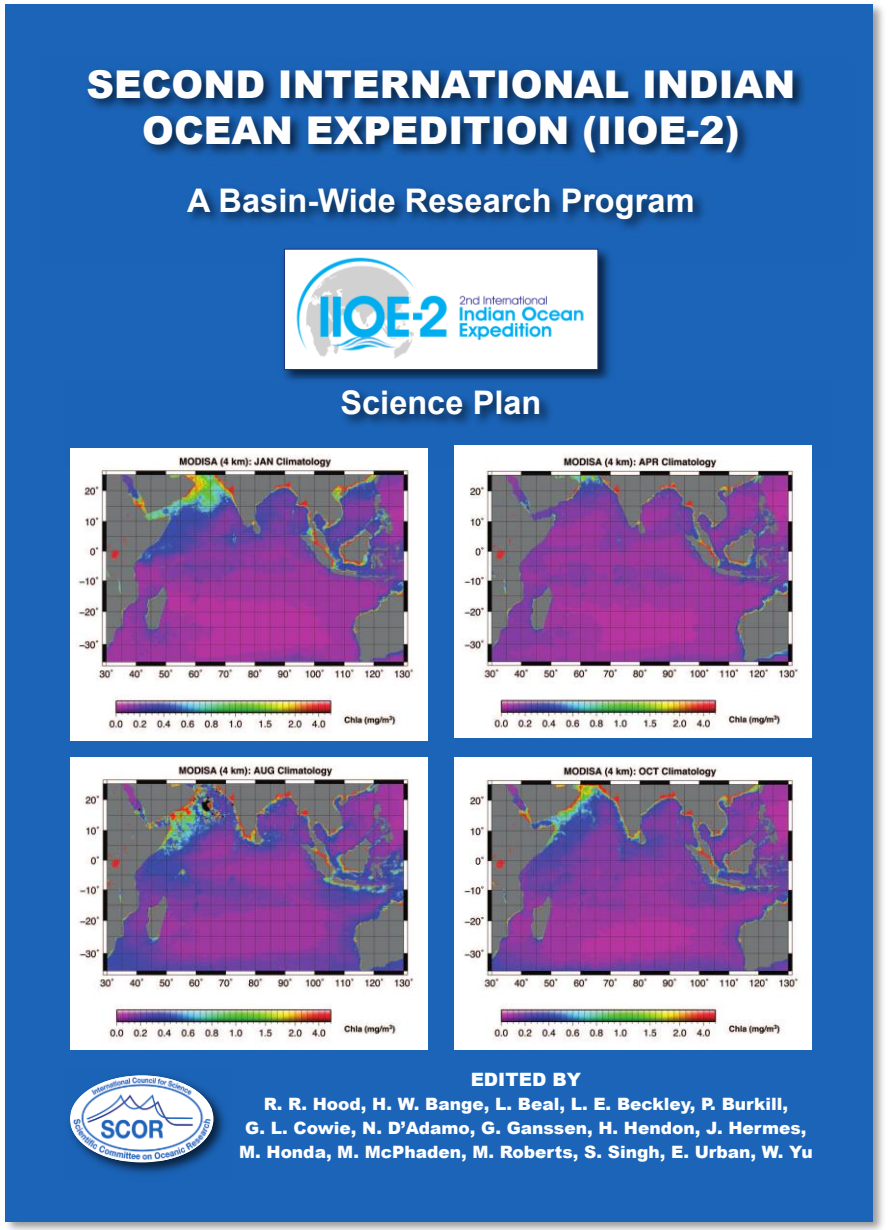
Table of Contents

BACKGROUND AND MOTIVATION

- Background on IIOE-2
- **Development of the IIOE-2 Science Plan**
- Development of the IIOE-2 Implementation Strategy

Development of the IIOE-2 Science Plan:

- The IIOE 50 year anniversary symposium in 2015 and IIOE-2 discussions were initiated in April 2011 at an IMBER SSC meeting in Marseilles (discussions with Ed Urban/SCOR).
- A seminal meeting followed in Cape Town in October 2012 leading to the IOC “Reference Group” meetings (led by Nick D’Adamo).
- SCOR, IOC and IOGOOS informally assumed leadership of the IIOE-2 planning process.
- ***The IIOE-2 Science Plan was commissioned by SCOR.***
- The development was based on the IOC “Reference Group” planning meetings and national meetings in 2013 and 2014.
- The plan was finalized and printed for Goa Symposium in November, 2015.
- Note that many of the authors are still involved!



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Overarching goal:

The overarching goal of IIOE-2 is to advance our understanding of interactions among geologic, oceanic and atmospheric processes that give rise to the complex physical dynamics of the Indian Ocean region, and determine how those dynamics affect climate, extreme events, marine biogeochemical cycles, ecosystems and human populations.

Six Research Themes:

Theme 1: Human Impacts

Theme 2: Boundary current dynamics, upwelling variability and ecosystem impacts

Theme 3: Monsoon variability and ecosystem response

Theme 4: Circulation, climate variability and change

Theme 5: Extreme events and their impacts on ecosystems and human populations

Theme 6: Unique geological, physical, biogeochemical and ecological features of the Indian Ocean

The IIOE-2 community believes that more action is needed to address Theme 1. But it is also important to emphasize that the Addendum does not supersede the IIOE-2 Science Plan.

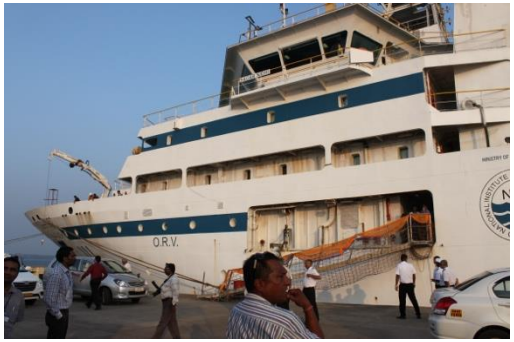
MAJOR IIOE-2 MILESTONES AND CHALLENGES

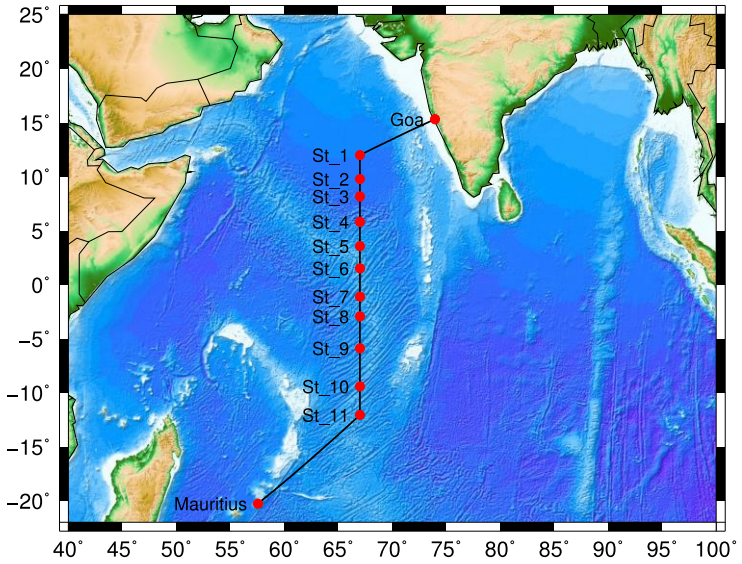
- **IIOE-2 50Th Anniversary Symposium and First Official Cruise**
- **Joint India-Australia International Project Office Established**
- **Establishment of the Early Career Scientists Network**
- **IOC, IOGOOS and SCOR Approve 5 year Extension**
- **Impacts of the COVID-19 Pandemic**

IIOE-2 50Th Anniversary Symposium and First Official Cruise

- **50th Anniversary Symposium** convened at NIO in Goa, Nov. 30 – Dec. 4, 2015.
- "Dynamics of the Indian Ocean: Perspective and Retrospective".
- >400 participants.
- Special sessions following IIOE-2 Science Plan research themes.

- **First official cruise:** Goa to Mauritius on the NIO vessel *RV Sagar Nidhi*.
- Departed December 5, 2015.
- Strong international participation.
- The first of several Indian IIOE-2 cruises and many cruises funded by other countries.





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Joint India-Australia IPO Established:

INCOIS, Hyderabad

Dr. Satya Prakash

Bureau of Meteorology, Perth

Dr. Nick D'Adamo

Early Career Scientists Network Established:

- The IIOE-2 Early Career Scientist Network (ECSN) originated as the result of a special session entitled "Recent Results from Early-Career Scientists in Indian Ocean Research" that was convened at the IIOE 50th Anniversary Symposium.

- The IIOE-2 ECSN currently includes >100 active registered members from 17 countries.

SCOR, IOC, IOGOOS Approve 5 Year Extension:

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United Nations Educational, Scientific and Cultural Organization

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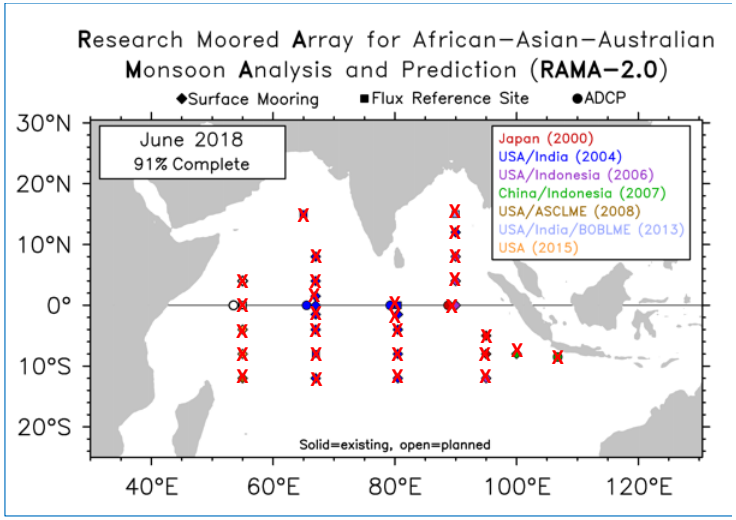
GLOBAL OCEAN OBSERVING SYSTEM FOR INDIAN OCEAN

Impact of Covid-19 Pandemic:

- 2020 International Indian Ocean Science Conference cancelled just weeks before it was supposed to be convened at NIO in Goa.
- Australia node of the IPO closed (IOC/Perth office defunded).
- India node lost key personnel.
- Cruises and research activity came to a screeching halt in Spring of 2020.
- Example: Severe negative impacts on RAMA due to cancelation of mooring deployment and servicing cruises. All RAMA moorings were offline except one as of February 2023.

Dr. Satya Prakash (1979 – 2021)



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PROGRESS AND CURRENT STATUS

- **Rapid recovery**
- **Official Projects and International Participation**
- **Working Groups and Research Themes**
- **Synthesis Papers, Books and Special Issues**
- **Science Highlights**

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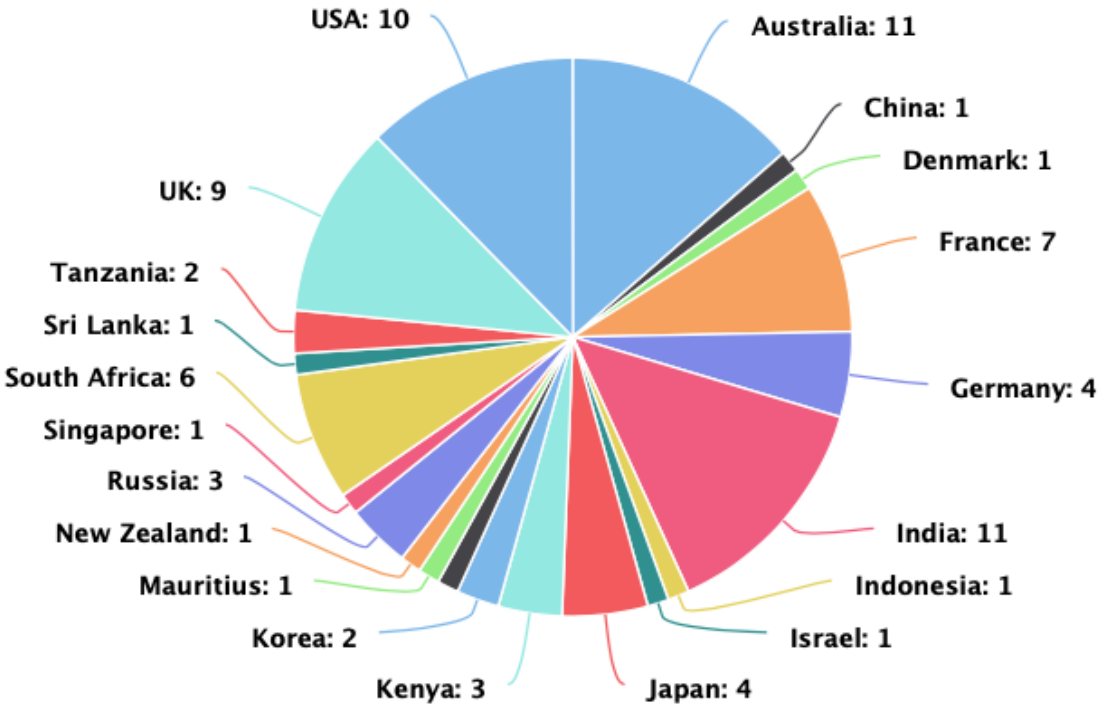
Rapid Recovery:

- IPO at INCOIS / Hyderabad gets new leadership (Aneesh Lotiker / Kiran Kumar)
- Picks up the slack from loss of the Australia IPO
- Nick continues involvement providing support for IIOSC 2023, IRF, and Hyderabad meeting

- There has been a rapid resumption of cruise activity over the past 2 years
- Example: Several US Expeditions to the Indian Ocean have recently happened and/or are planned for the near future (NSF didn't cancel any projects)
- Servicing of RAMA moorings has accelerated rapidly over the last year with more than half of the array (14 moorings) now functioning
- ***This resumption of IIOE-2 activity and renewed momentum is one of the primary motivations behind this request for an extension – we are on a role and would like to keep it going***

Endorsed Projects:

- >50 Endorsed projects with 20 Countries involved
- USA, India, and Australia leading the way



IOGOOS
GLOBAL OCEAN OBSERVING SYSTEM FOR INDIAN OCEAN

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Status of Working Groups and Research Themes:

Working Groups:

WG 1: Science and Research (Raleigh Hood and Hermann Bange) Active

WG 2: Data and Information Management (Cindy Chandler / Now Pattabbhi Rama Rao and Harrison Ong'Anda) Active

WG 3: Operational Coordination (Shailesh Nayak and Rajan Sivaramakrishnan / Now the IPO) Active

Six Research Themes:

Theme 1: Human Impacts New leadership - Halina Kobryn

Theme 2: Boundary current dynamics, upwelling variability and ecosystem impacts (P. N. Vinahachandran and Yukio Masumoto) Active

Theme 3: Monsoon variability and ecosystem response (Andrian Matthews and Joaquim Goes) Active

Theme 4: Circulation, climate variability and change (Amit Tandon and Helen Phillips) Active

Theme 5: Extreme events and their impacts on ecosystems and human populations (Chari Pattiaratchi) Active

Theme 6: Unique geological, physical, biogeochemical and ecological features of the Indian Ocean (Jerome Dyment) New Leadership - Lynnath Beckley and Marie-Alexandrine Sicre

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EGU Special Issue on IIOE-2:

- **We put together a set of synthesis papers on the Indian Ocean and published them as a special issue of EGU Journals.**
- Guest editors: Raleigh Hood and Hermann Bange
- Inspired by IIOE-2 Science Plan Research Themes
- **6 synthesis papers published**

Löscher, C. R., 2021, Reviews and syntheses: Trends in primary production in the Bay of Bengal–is it at a tipping point?: Biogeosciences, v. 18, no. 17, p. 4953-4963.

Nimit, K., 2021, Ideas and perspectives: Ushering the Indian Ocean into the UN Decade of Ocean Science for Sustainable Development (UNDOSSD) through marine ecosystem research and operational services–an early career's take: Biogeosciences, v. 18, no. 12, p. 3631-3635.

Pattiaratchi, C., van der Mheen, M., Schlundt, C., Narayanaswamy, B. E., Sura, A., Hajbane, S., White, R., Kumar, N., Fernandes, M., and Wijeratne, S., 2022, Plastics in the Indian Ocean–sources, transport, distribution, and impacts: Ocean science, v. 18, no. 1, p. 1-28.

Phillips, H. E., Tandon, A., Furue, R., Hood, R., Ummenhofer, C. C., Benthuysen, J. A., Menezes, V., Hu, S., Webber, B., and Sanchez-Franks, A., 2021, Progress in understanding of Indian Ocean circulation, variability, air–sea exchange, and impacts on biogeochemistry: Ocean Science, v. 17, no. 6, p. 1677-1751.

Tegtmeier, S., Marandino, C., Jia, Y., Quack, B., and Mahajan, A. S., 2022, Atmospheric gas-phase composition over the Indian Ocean: Atmospheric Chemistry and Physics, v. 22, no. 10, p. 6625-6676.

Vinayachandran, P. N. M., Masumoto, Y., Roberts, M. J., Huggett, J. A., Halo, I., Chatterjee, A., Amol, P., Gupta, G. V., Singh, A., and Mukherjee, A., 2021, Reviews and syntheses: Physical and biogeochemical processes associated with upwelling in the Indian Ocean: Biogeosciences, v. 18, no. 22, p. 5967-6029.

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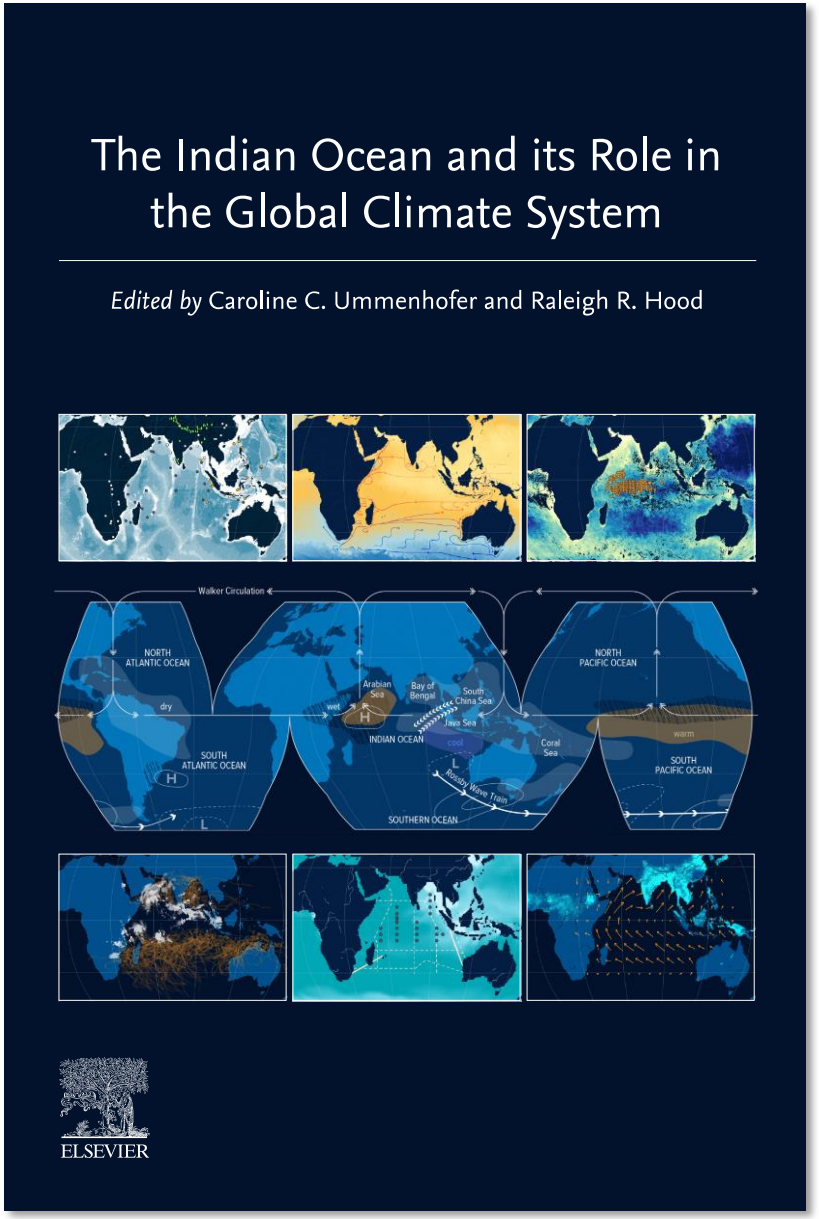
Elsevier Book:

- **We have finished an interdisciplinary book of synthesis chapters on the Indian Ocean.**
- **Published by Elsevier in April 2024.**
- Editors: Caroline Ummenhofer and Raleigh Hood
- **20 Synthesis Chapters:**

1. Raleigh Hood et al., “Introduction to the Indian Ocean”
2. Timothy Walker, “A brief historical overview of the Indian Ocean”
3. Caroline Ummenhofer et al., “Past, present and future of the South Asian monsoon”
4. Charlotte Demott et al., “Intraseasonal variability in the Indian Ocean region”
5. Toshi Yamagata et al., “Climate phenomena of the Indian”
6. Ming Feng et al., “Extreme events in the Indian Ocean: Marine heatwaves, cyclines, and tsunamis”
7. Caroline Ummenhofer et al., “Indian Ocean impact on regional and global climate”
8. Helen Phillips et al., “Indian Ocean circulation”
9. Janet Sprintall et al., “Oceanic basin connections”
10. Tomoki Tozuka et al., “Decadal variability of the Indian Ocean and its predictability”
11. Francis Marsac et al., “Indian Ocean primary productivity & fisheries variability”
12. Raleigh Hood et al., “Oxygen, Carbon and pH variability in the Indian Ocean”
13. Raleigh Hood et al., “Nutrient, phytoplankton and zooplankton variability in the Indian Ocean”
14. Hermann Bange et al., “Air-sea exchange and its impacts on biogeochemistry in the Indian Ocean”
15. Carolin Loscher et al., “Microbiology of the Indian Ocean”
16. Faiza Al-Yamani et al., “Physical and biogeochemical characteristics of Indian Ocean marginal seas”
17. Michael McPhaden et al., “The Indian Ocean observing system (IndOOS)”
18. Toshi Shinoda et al., “Modeling the Indian Ocean”
19. Mahyar Mohtadi et al., “Paleoclimate evidence of Indian Ocean variability across a range of timescales”
20. MK Roxy et al., “Future projections for the tropical Indian Ocean”



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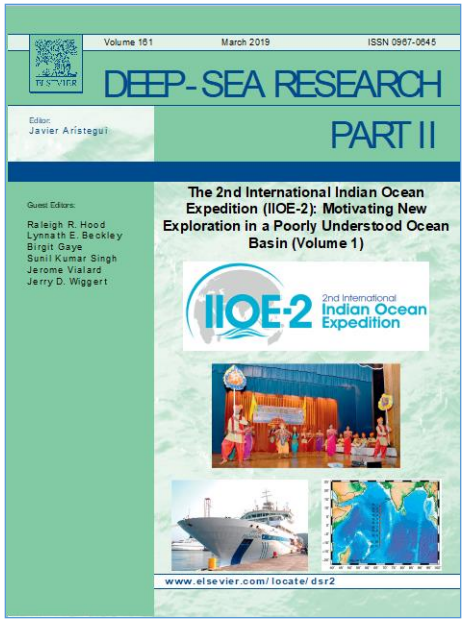
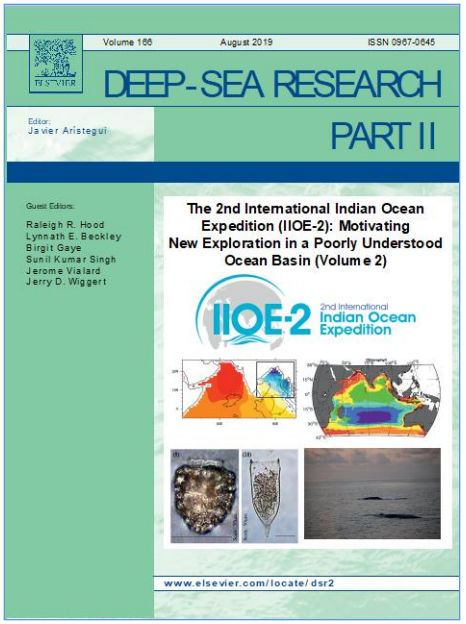
Deep-Sea Research Special Issues on IIOE-2

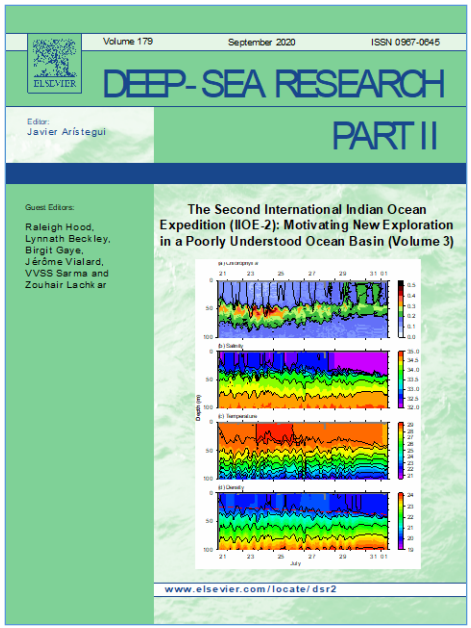
- **We put together a set of special issues on IIOE-2 for publication in DSR II. > *70 papers published thus far.***

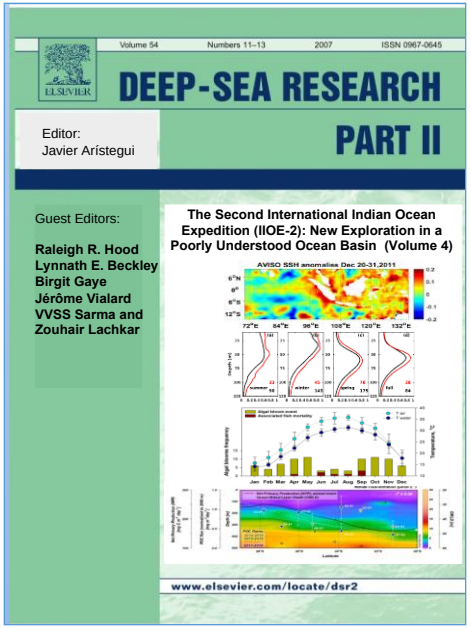
- "The 2nd International Indian Ocean Expedition (IIOE-2): Motivating New Exploration in a Poorly Understood Basin"

- **Guest editor team volumes 1 and 2:**
  1. Raleigh Hood (rhood@umces.edu)
  2. Jerry Wiggert
  3. Lynnath Beckley
  4. Birgit Gaye
  5. Jerome Vialard
  6. Sunil Singh
- **Guest editor team volumes 3, 4 and 6:**
  1. Raleigh Hood (rhood@umces.edu)
  2. Zouhair Lachkar
  3. Lynnath Beckley
  4. Birgit Gaye
  5. P. N. Vinyachandran
  6. VVSS Sarma
- **Volume 5 is focused on the 2019 R. V. Investigator Cruise along 110°E with Guest editors:**
  1. Lynnath Beckley,
  2. Raleigh Hood
  3. Peter Thompson
- **Guest editor team volume 7 (closes Feb. 15, 2025):**
  1. Raleigh Hood (rhood@umces.edu)
  2. Laure Resplandy
  3. Lynnath Beckley
  4. Birgit Gaye
  5. P. N. Vinyachandran
  6. VVSS Sarma
- ***Application for Volume 8 was submitted in October and will be focused on the 2022 BLOOFINZ Cruise, with with a submission deadline of July 15, 2025.***









Some Scientific Highlights:

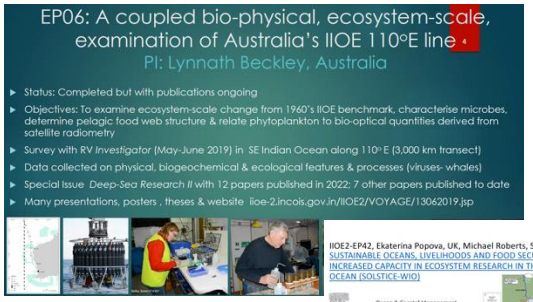
- A COUPLED BIO-PHYSICAL, ECOSYSTEM-SCALE, EXAMINATION OF AUSTRALIA'S INTERNATIONAL INDIAN OCEAN EXPEDITION 110°E LINE (IIOE2-EP06)

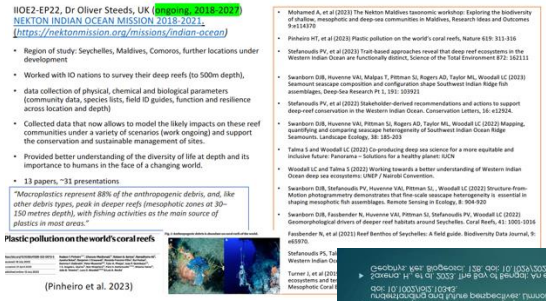
- SUSTAINABLE OCEANS, LIVELIHOODS AND FOOD SECURITY THROUGH INCREASED CAPACITY IN ECOSYSTEM RESEARCH IN THE WESTERN INDIAN OCEAN (SOLSTICE-WIO) (IIOE2-EP42)

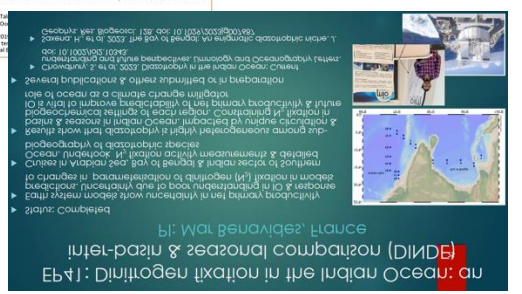
- NEKTON INDIAN OCEAN MISSION (IIOE2-EP22)

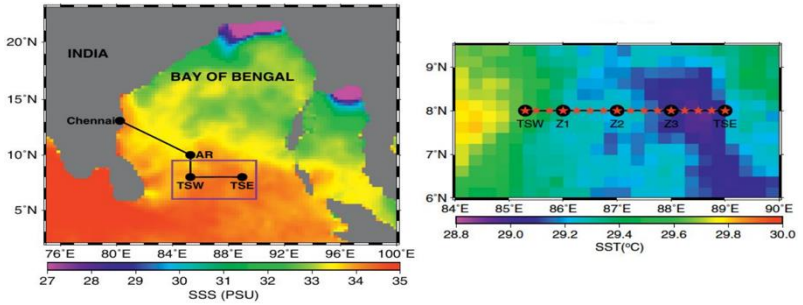
- DINITROGEN FIXATION IN THE INDIAN OCEAN: AN INTERBASIN AND SEASONAL COMPARISON (IIOE2-EP41)

- BoBBLE: BAY OF BENGAL BOUNDARY LAYER EXPERIMENT









IIOE-2 SCIENCE 2025-2030

- **Scientific Theme 1: Human Impacts**
- **Knowledge Gaps and Challenges Related to Societal Benefits and Human Impacts**
- **New Initiatives (KUDOS, COLaB, Marginal Seas Research)**
- In Situ Observations, Remote Sensing, Modeling and Assimilation

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IIOE-2 SCIENCE 2025-2030

- The IIOE-2 has structured its research around six scientific themes.

- The core questions from theme 1 (Human Impacts) are reiterated in the Addendum because they articulate many of the challenges and research questions that will be prioritized in the final phase of IIOE-2 (2025 – 2030).

- ***The IIOE-2 community believes that more action is needed to address the core questions of Theme 1.***

- ***But it is also important to emphasize that this document does not supersede the IIOE-2 Science Plan. The science priorities identified in the Science Plan will continue to be priorities in the final phase of IIOE-2.***

- ***Rather, this document highlights areas of the Science Plan that will be prioritized in the final phase of IIOE-2, and describes some new initiatives and opportunities that have emerged under IIOE-2 that did not exist when the Science Plan was written.***

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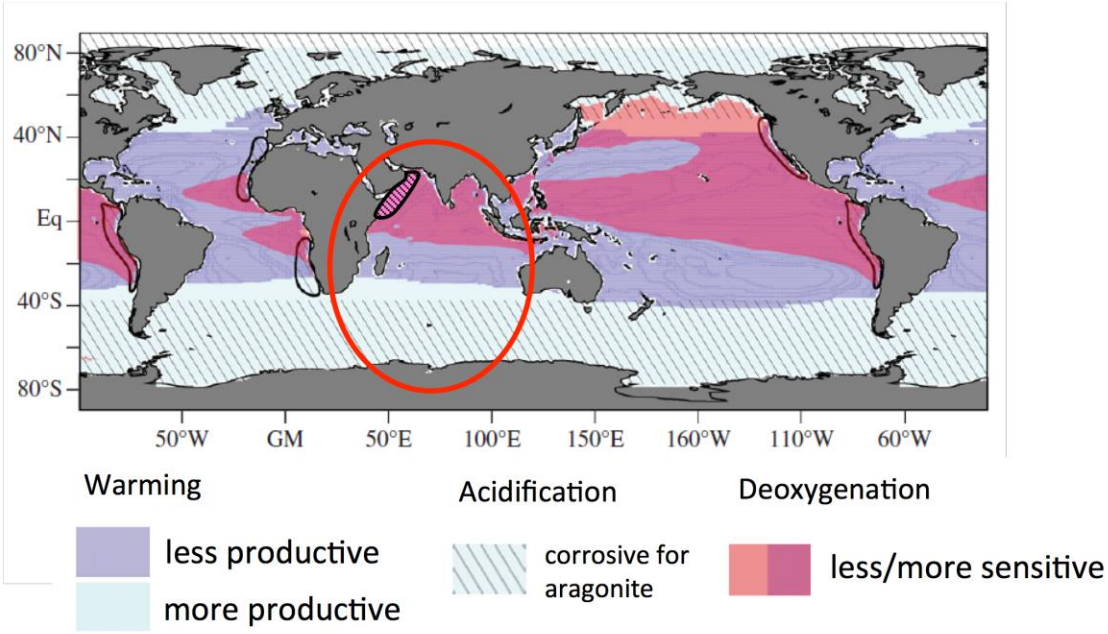
Theme 1: Human Impacts:

Core questions:

- How are human-induced ocean stressors (for example, warming, sea-level rise, deoxygenation, acidification, eutrophication, atmospheric and plastic pollution, coastal erosion and overfishing) impacting the biogeochemistry and ecology of the Indian Ocean?

- How, in turn, are these impacts affecting human populations?



KNOWLEDGE GAPS AND CHALLENGES RELATED TO SOCIETAL BENEFITS AND HUMAN IMPACTS:

COASTAL MONITORING AND META-DATA SHARING FROM EEZS

- The IIOE-2 Science Plan emphasizes the need for coastal monitoring, and data sharing. But the reality is that many Indian Ocean rim nations have national policies that prohibit sharing of data from their Exclusive Economic Zones (EEZs).

- The strategy that will be pursued in the final phase of IIOE-2 will be to promote meta-data sharing with the IIOE-2 IPO, if full data access is not feasible, and also development of new, low-cost coastal monitoring efforts, especially in developing countries (see the new research initiative COLaB below).

- With this strategy, it will be possible to discover the data that is being collected in the EEZs of all Indian Ocean rim nations that are involved in IIOE-2.

KNOWLEDGE GAPS AND CHALLENGES RELATED TO SOCIETAL BENEFITS AND HUMAN IMPACTS:

MARINE SPATIAL PLANNING

- IOC of UNESCO defines Marine Spatial Planning as, “a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives.”

- The final phase of IIOE-2 will focus on engaging with and promoting MSP efforts in the Indian Ocean, providing the support and guidance needed to ensure their success.

KNOWLEDGE GAPS AND CHALLENGES RELATED TO SOCIETAL BENEFITS AND HUMAN IMPACTS:

SCIENTIFIC UNDERSTANDING AND ENGAGEMENT OF THE WESTERN INDIAN OCEAN, THE EASTERN BAY OF BENGAL AND MARGINAL SEAS RESEARCH COMMUNITIES

- The IIOE-2 has not successfully engaged some Indian Ocean rim countries and island nations, notably, from the western and northwestern Indian Ocean (e.g., Saudi Arabia, Oman, Kenya, Tanzania), and the central and eastern Bay of Bengal (e.g., Sri Lanka, Thailand, Malaysia).

- By expanding participation from these countries, the IIOE-2 aims to promote and support collaborative research in the coastal regions, marginal seas, and open ocean environments of the Indian Ocean.

- This effort will lead to new discoveries, enhance our understanding, and improve our ability to monitor and predict the impacts of anthropogenic influences on valuable marine resources.

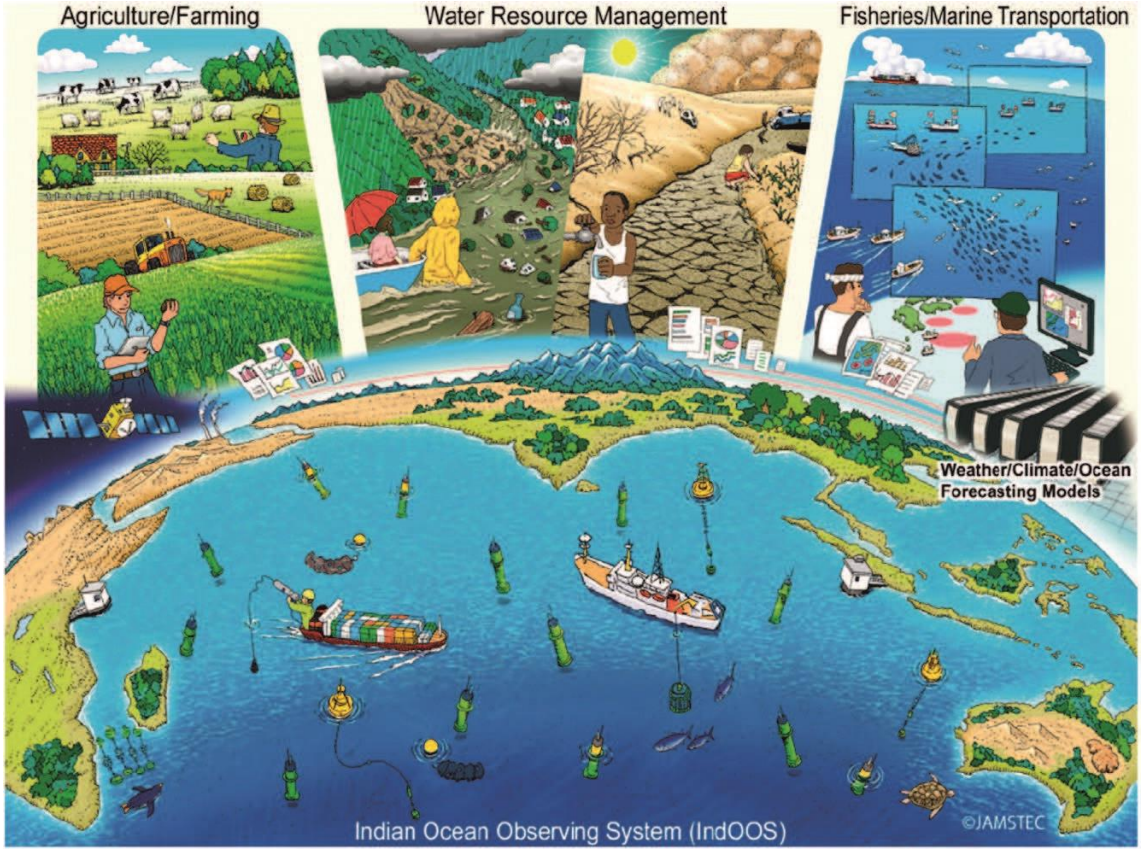
KNOWLEDGE GAPS AND CHALLENGES RELATED TO SOCIETAL BENEFITS AND HUMAN IMPACTS:

COMMUNITY INVOLVEMENT

- In its final phase, IIOE-2 will foster collaboration across borders, to bridge the gap between global researchers and local stakeholders, promoting co-design and co-leadership.

- IIOE-2 will explicitly promote regional collaboration, where different countries, especially smaller nations or island states, have equal opportunities to contribute to the research agenda.

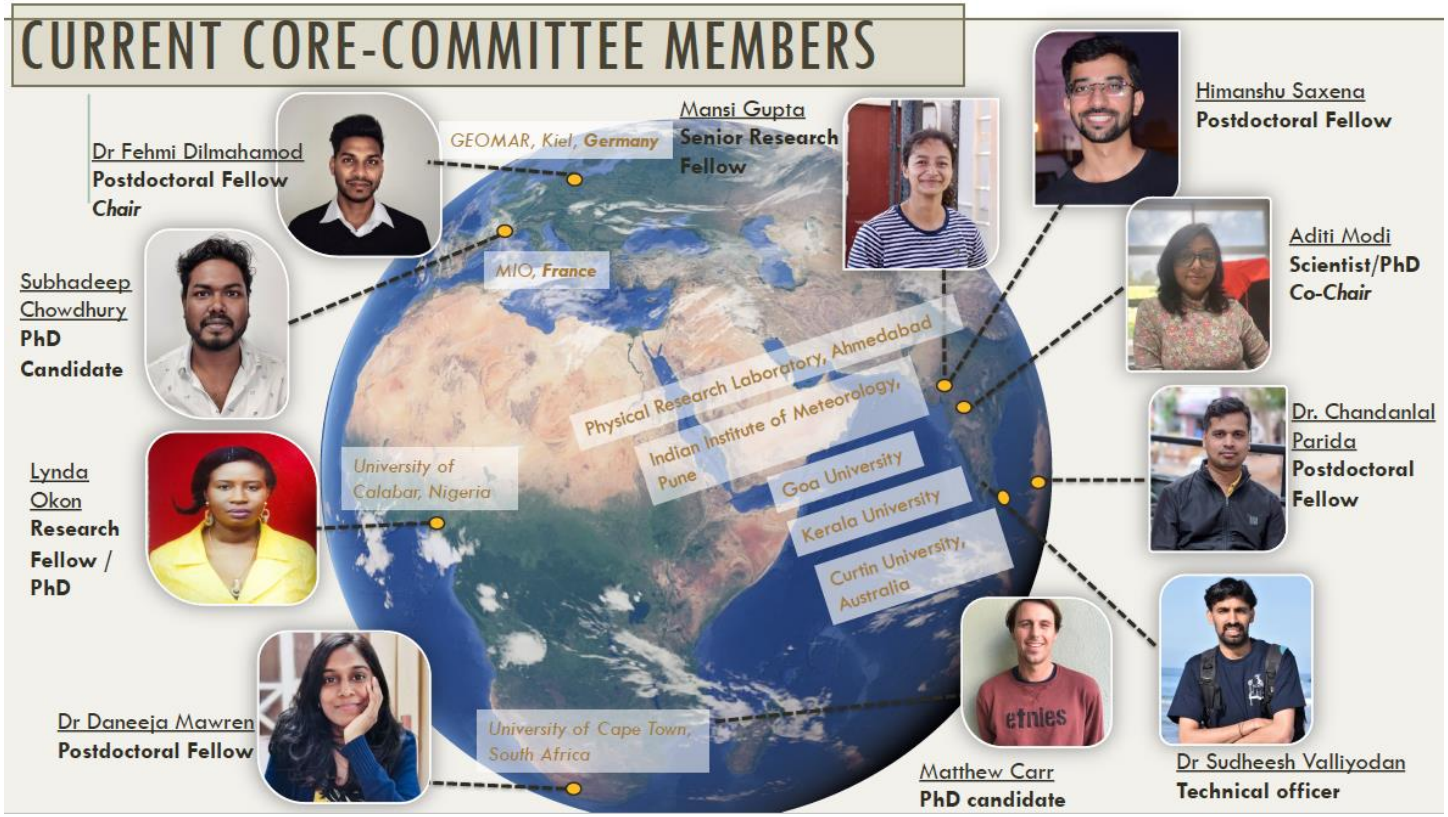
- Open ocean research and EEZ-focused studies can coexist, with the IIOE-2 providing an equitable framework for knowledge exchange, access to international expertise, and resources.



KNOWLEDGE GAPS AND CHALLENGES RELATED TO SOCIETAL BENEFITS AND HUMAN IMPACTS:

ECSN PROMOTION

- The IIOE-2 Early Career Scientist Network represents the future of Indian Ocean research. In its final phase, IIOE-2 aims to ensure that this next generation of scientists will be successful and maintain the research momentum generated by IIOE-2.

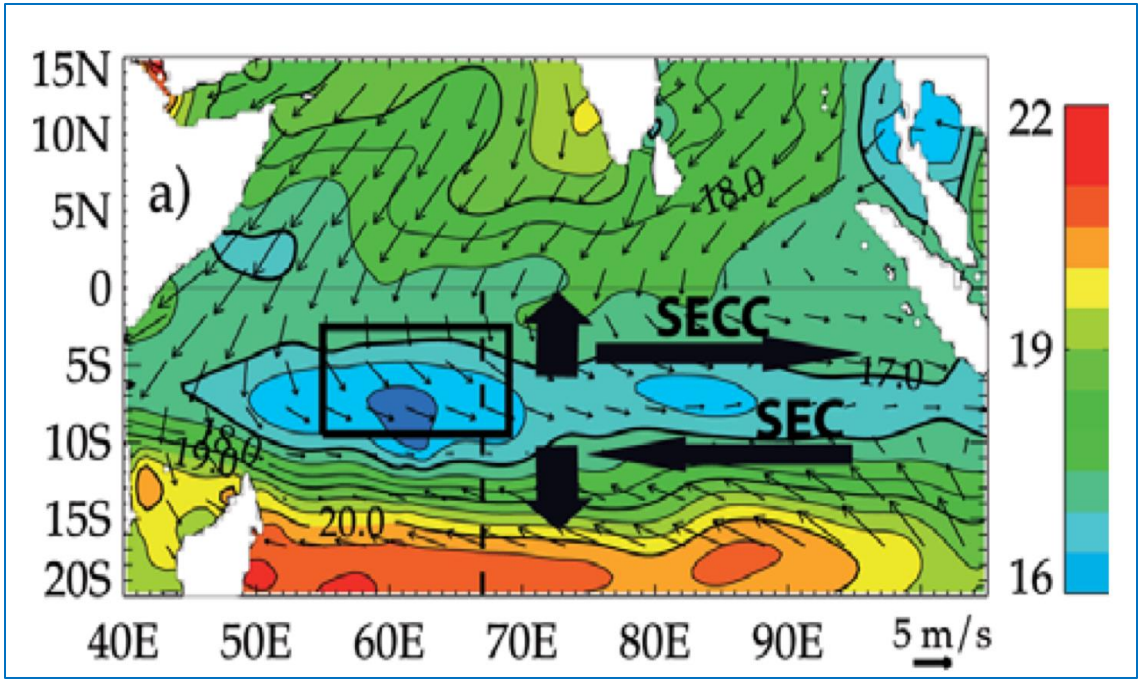


Current IIOE-2 ECSN core committee members.

NEW INITIATIVES:

KUDOS (Korea-US Indian Ocean Scientific Imperatives):

- Scientific focus on the Seychelles-Chagos Thermocline Ridge.
- ***Have institutionalized KUDOS cruises through 2026.***
- ***Will support RAMA and other international collaborative efforts.***
- ***International participation encouraged.***



KUDOS Plan available at:
https://kiost-noaa-lab.wixsite.com/kudos2018

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NEW INITIATIVES:

COLaB (Coastal Observation Lab in a Box)

Instruments for training for physical, biological and biogeochemical coastal observations

- Low Cost
- Portable
- Open source
- Minimal infrastructure needs
- Diverse applications
- Complementary to moored systems and remote sensing
- Data management and modeling packages
- Regional hubs for instrument cross-calibration
- In-person training and online support

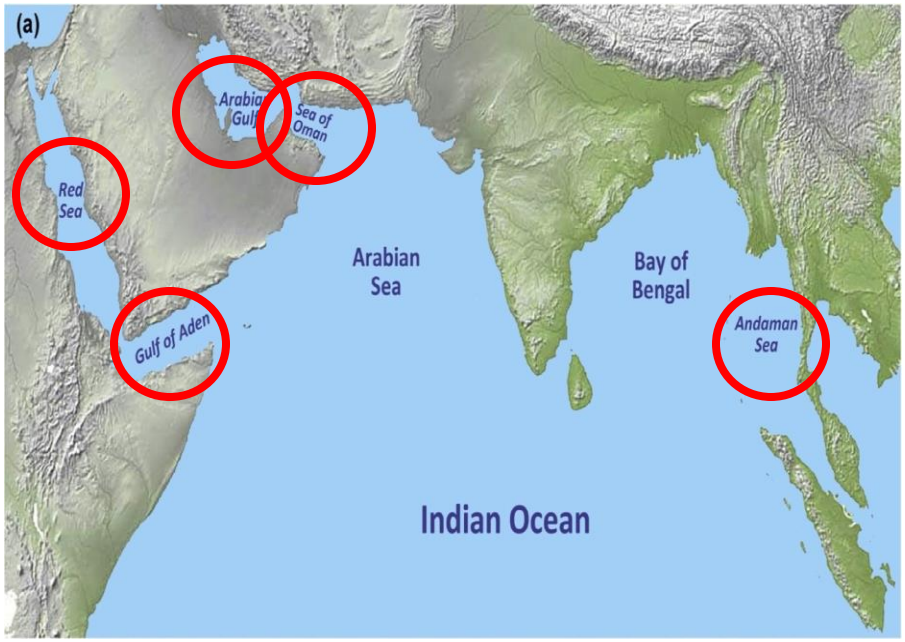
In its final phase IIOE-2 will focus on expanding coastal monitoring efforts in Indian Ocean rim countries and making the data from these efforts accessible to the scientific and stakeholder communities. The IIOE-2 community believes that there is a major opportunity to deploy COLaB as leverage for building a sustainable regional network for cross-validated coastal oceanographic data collection and also for building capacity and for training multi-skilled coastal oceanographers.

NEW INITIATIVES:

Marginal Seas Research Initiative

- The major marginal seas of the Indian Ocean include the Andaman Sea, the Arabian/Persian Gulf, the Gulf of Aden, the Red Sea, and the Sea of Oman.
- These seas are critical to regional climates, marine biodiversity, and human livelihoods.
- However, they remain underexplored compared to other parts of the Indian Ocean.
- This research initiative aims to address this gap by conducting a comprehensive study of the marginal seas of the Indian Ocean to enhance our understanding of these unique, complex, and dynamic systems.

Motivating a Marginal Seas Research Initiative will not only advance scientific understanding in these understudied regions of the Indian Ocean, but will also provide new opportunities for scientific engagement of Indian Ocean rim countries that are not currently actively participating in IIOE-2. Achieving these goals will be key to establishing the legacy of IIOE-2.



INTEGRATION

- UN Decade of Ocean Science for Sustainable Development
- New IOC Sub-Commission: IOCINDIO
- WCRP My Climate Risk Program
- CoastPredict
- Communication
- Data and Information Management
- Training and Education

CONCLUSIONS AND LEGACY

- ***The main focus of the research that will be carried in the final phase of IIOE-2 will be aimed at better understanding the impacts of multiple stressors on coastal environments and efforts will be motivated to communicate these findings to decision makers.***

- ***The success of IIOE-2 will be gauged not just by how much it advances our understanding of the complex and dynamic Indian Ocean system, but also by how it contributes to the sustainable development of marine resources, environmental stewardship, ocean and climate forecasting, and training of the next generation of ocean scientists from the region. This vision of success can be fully realized in the final phase of IIOE-2.***

Thank You!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